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Metrology Challenges for High Energy Density Science Target Manufacture

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Abstract

Currently, High Energy Density Science (HEDS) experiments are used to support and qualify predictive physics models. These models assume ideal conditions such as energy (input) and device (target) geometry. The experiments rely on precision targets constructed from components with dimensions in the millimeter range, while having micrometer-scale, functional features, including planar steps, sine waves, and step-joint geometry on hemispherical targets. Future target designs will likely have features and forms that rival or surpass current manufacturing and characterization capability. The dimensional metrology of these features is important for a number of reasons, including qualification of sub-components prior to assembly, quantification of critical features on the as-built assemblies and as a feedback mechanism for fabrication process development. Variations in geometry from part to part can lead to functional limitations, such as unpredictable instabilities during an experiment and the inability to assemble a target from poorly matched sub-components. Adding to the complexity are the large number and variety of materials, components, and shapes that render any single metrology technique difficult to use with low uncertainty. Common materials include metal and glass foams, doped transparent and opaque plastics and a variety of deposited and wrought metals. A suite of metrology tools and techniques developed to address the many critical issues relevant to the manufacture of HEDS targets including interferometry, x-ray radiography and contact metrology are presented including two sided interferometry for absolute thickness metrology and low force probe technology for micrometer feature coordinate metrology. LLNL-PROC-410774

1 Challenges for target metrology

As mentioned above, HEDS targets are comprised of millimeter scale components of a large variety of materials. Due to the scale of the system being investigated, the geometric tolerances of the parts and subsequent assembly are often at the micrometer level or below and are difficult to qualify using commercial equipment for most cases. An example of critical features in need of characterization is shown in Figure 1. Critical features include thickness, flatness and surface variation (i.e. surface finish over a wide spatial frequency range).

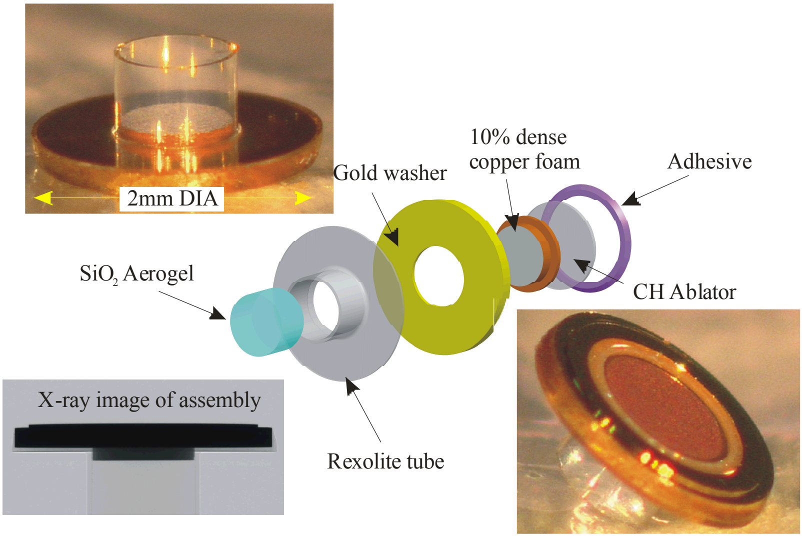

Figure 1: Example of a HEDS target assembly comprised of 10% dense Cu foam, CH ablator and 50 mg·cc^{-1} SiO_2 aerogel.

2 Current solutions

Coordinate and surface metrology for these types of assemblies is done with a combination of techniques, of which the three are outlined below. These provide the greatest potential improvement in accuracy, resolution and direct quantification for manufacturing quality control at the scales of interest.

1.1 X-ray imaging

One of the more difficult metrology issues is the verification of "as built" assemblies. Our primary tool for quantifying dimensional features, such as gaps and/or voids, is a combination of commercial and LLNL x-ray radiography systems. Figure 1 also illustrates an Xradia Micro XCT image of the assembled target using ~50 kVp x-ray energy with ~ 1.2 micrometer pixel size. Although a useful method for qualitative analysis, rigorous traceability for dimensional metrology remains a focus of effort and uncertainties below a couple of micrometers are beyond most system capabilities.

1.2 Contact based probe technology

Contact based probe metrology represents one of the most common methods of determining feature geometry at conventional scales. However, as the probe scale and probing force goes down, the affects of surface physics, such as water layers, contamination and charging can dominate the uncertainty of any measurement. Current studies of low force, high-aspect ratio contact probe technology have been an ongoing collaborative effort with industrial and academic partners. One type of probe technology being studied utilizes a resonant system which oscillates a fiber probe creating a standing wave, which is used to locate the surface [2]. Improvements to the sensing electronics and manufacture have shown repeatability to the ± 10 nm level.

1.3 White light interferometry

Conventional, micro, phase measuring interferometers are very effective instruments for inspecting precision surfaces and micro-structures. Commercialized hardware and software limit the use in general practice to single surface interrogations. Integrating an optical package into the work stage can increase the usefulness to include 3 dimensional measurements. The retrofit combines a series of mirrors to allow both, front and rear surfaces to be viewed by the instrument objective and interferometer system (Figure 3). The dual-imaging optic package is designed to transmit adjacent wave fronts, each taking different optical paths. The front-surface optical path length (OPL) is diverted to match the OPL of the rear-surface which reflected off of two required surfaces. Precision construction of the roof mirrors and prism provides two equal optical paths (1/4 wave). In practice, the two work piece surfaces (front and rear) are viewed side-by-side. The instrument is able to scan the front surface, then the rear surface.

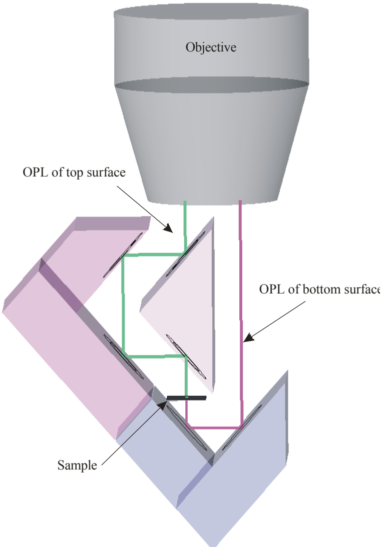

Figure 2: Double sided interferometer for combined thickness and flatness measurement.

The two data collection files are separated by the absolute distance between the surfaces. Newly developed system software manages the data sets to correct parity and visual representations. The system is easily calibrated by interrogating an artifact with thin, metal coating. A coating mask is used to restrict the thin-film deposit to a sub-region of the front-surface FOV. The Thin-film and sub-region are scanned and compared to the rear side of the film which is transmitted through the supporting optic. A primary reference surface is defined by the uncoated front-side plane. This plane is analogous to the rear-side of the coating only displaced by the sum of the effect (index of refraction and thickness) of the supporting optic and the geometric errors built in to the optics package. The hardware and software can be used to measure total thickness variations of metal films and precision products. It can also be used to measure indices of thin transparent materials.

3 Conclusions and future work

The three techniques outlined in this report represent a combination of metrology instruments currently being used and/or developed to facilitate manufacture of HEDS targets. Dimensional requirements of parts and assemblies continue to push “state-of-the-art” metrology and represent a large research and development need. Coordinate metrology of micrometer features at nanometer resolution remains on a critical path to producing and understanding fundamental science.

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References:

[1] Bauza, M D, *et al. Rev. Sci. Instrum.* **76** (9) 2005.